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AN ENGINEERING STUDY and PRELIMINARY DESIGN

of a

ONE MAN PROPULSION DEVICE

for

LUNAR and FREE-SPACE ENVIRONMENTS

SUMMARY REPORT

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A. INTRODUCTION

A great deal of attention has been paid in recent years to methods for transporting astronauts to the surface of the Moon and to the kinds of equipment and supplies which will allow them to survive and return to Earth safely after having completed their mission. Similarly, much work has been done in determining the kinds of tools and equipment an astronaut needs in order to carry out his assigned tasks during the missions. However, it has only been very recent that serious attention has been focussed on the problems of astronaut personal mobility in conjunction with the lunar missions -- yet this is one of the most crucial factors which influence the benefits to be derived from such missions.

To get the astronauts to the lunar surface and return is, of course, a prime requisite; however, for the mission to be truely worthwhile, the astronauts must be able to perform useful tasks while on the Moon's surface. In addition to gathering samples and making engineering and scientific observations of the lunar surface and its environs, the astronaut will be called upon the explore the surrounding topography -- since this is one of the primary reasons for his being there in the first place. Without adequate personal mobility and insufficient lunar surface locomotion capabilities, the astronaut will be severely handicapped in carrying out his role in the mission. The subject of astronaut personal mobility and locomotion is therefore an important and timely consideration in the lunar program.

The consideration of personal locomotion need not be restricted to locomotion on the lunar surface alone, since there may be occasions in the lunar orbit or translunar portions of the mission wherein personal mobility of the astronauts will play a key role in determining mission success (for example, an emergency rescue operation in the case of a docking mishap between LEM and the Apollo Command Module).

With the advent of space stations and interplanetary travel, the frequency of extra-vehicular activities will increase (for example, to make necessary repairs, effect crew transfers, etc.). The use of supplemental locomotion aids will therefore play an increasing role in the free space activities. Without such aids, vehicle to vehicle transfers will be virtually impossible and vehicle maintenance will be almost prohibitive.

To properly assess the personal locomotion problems associated with the lunar missions, a six-month study was initiated of these missions, the needs for personal locomotion devices in conjunction therewith, the potential systems concepts which might fulfill those needs, and preliminary designs have been accomplished on two of the more promising of these concepts (i.e., one for free space applications and the other for lunar surface applications). This report summarizes the results of the study, which was performed under NASA Contract NAS 9-2065.

The report describes the objectives of the study, the method of approach which was used, a brief review of the significant results which were achieved, and recommendations for follow-on work which should be undertaken.

B. STUDY OBJECTIVES

The subject program involved the study of one man propulsion devices which could be used as a means of increasing the range of manned lunar exploration and for use in extravehicular maneuvers in free space.

The stipulated operational objectives of such devices were as follows:

1) To supplement the inherent locomotive capabilities of a man in a pressure suit and render it possible for him to traverse those portions of the lunar surface that are not accessible by surface vehicles or man on foot.

2) To provide a man in a pressure suit a means of extravehicular maneuvering in free space. (The free space activity would include functions associated with maintenance of a vehicle or transfer from one vehicle to another).

The specific objectives of the study program were as follows:

A) To define the problem areas associated with the operational objectives (noted above) of one man propulsion devices.

B) To examine potential methods for solving the problems noted in (A).

C) To develop a preliminary design of a propulsion device (or devices) which will best fulfill the early one man locomotion needs in space.

For the lunar surface exploration mission, the astronaut would use the LEM, a lunar base, or an exploration vehicle as a point of departure and refueling base for excursions utilizing the propulsion device. Typical situations for using the device would be as follows:

A) For traversing flat, rough terrain where walking would be difficult and slow or where an exploration vehicle could not function.

B) For scaling steep and/or rough slopes such as are necessary for exploration of craters or fissures that could not be reached by the exploration vehicle.

C) For traversing flat, smooth areas where the use of the device could greatly increase the operational radius in a given time. (An example would be to make quick excursions to outstanding terrain features in the vicinity of the LEM).

A typical free space mission might be to transfer from the LEM to the Apollo Command Module across free space while in lunar orbit because of inability to perform the docking operation. In this case, it would be assumed that the two vehicles would be in the immediate vicinity of each other.

The performance capabilities of the propulsion device should allow the operator to hover, translate, rotate, rise and descend vertically, and boost himself into a trajectory in any direction in a controlled manner. The response to the operator's command must be sufficiently precise to allow the operator to consistently make a "soft" landing within a small, pre-selected area, even after a descent from a considerable height. Consideration should be given for providing the capability to perform rescue missions.

In addition to the above basic guidelines, it was stipulated that consideration be given to:

1) The integration and/or adaptation of the propulsion device to the fully pressurized suit.

2) Determining if the total propulsion device should include an integrated environmental control system or if the propulsion and stabilization systems should be built as one package and then used in conjunction with the presently contracted lunar portable life support system package.

3) The integration of the propulsion device into the space vehicle system. Of particular concern are:

    a) The ease of egress and ingress to a space vehicle such as the Apollo Command Module or the LEM of a man in a pressure suit utilizing the propulsion device.

    b) Methods of storing the propulsion device on board a space vehicle so as not to interfere with the operation of the vehicle.

4) Methods of performing comprehensive system qualification tests on the propulsion device.

5) Methods to be employed for crew training in the use of the device.

As evidenced in the study guidelines, the intent of the subject program was clearly to arrive at a single, rocket-powered, body-attached device which would suffice for both free space and lunar surface one man locomotion activities. However, to maintain a desirable degree of objectivity in the study, it was necessary to not only consider a number of rocket powered device concepts which are applicable to only one or the other of the operational environments, but also to examine other means of locomotion (i.e., in addition to rocket-powered devices), as well.

The guiding criterion which was used throughout the study was to maintain complete objectivity until such time as the analytical results dictated otherwise. In this manner, the results which were achieved were both logical and meaningful and the study objectives were achieved in a realistic manner.

C. RELATIONSHIP TO OTHER NASA EFFORTS

The subject study program was aimed mainly at the problems of one man locomotion associated with the Apollo/LEM missions. However, the basic information which has been generated is equally applicable to GEMINI, Lunar Bases, and interplanetary missions. The results, therefore, ought to be factored into present and future studies in all of these areas.

During the course of the subject study efforts, it became quite obvious that:

a) Proper attention has not been paid in past study efforts to the problems of astronaut maneuvering in the space missions which are currently contemplated (particularly the LEM and Lunar Base missions).

b) The design problems associated with a one man propulsion device cannot be isolated from those of the astronaut's protective garment, life support equipment, or the basic vehicles which he will use in the space missions.

c) Continuing studies of personal locomotion (in parallel with other studies of vehicles, missions, and crew systems) are required to keep the basic information generated in the present study updated as new facts are uncovered in the space program.

The importance of the one man propulsion device to the successful achievement of the Apollo missions cannot be overemphasized. On the basis of the presently known conditions which will be encountered on the lunar surface, the operational range of the astronauts will be severely limited if full reliance is placed upon pedestrian capabilities. Furthermore, even if a surface traveling vehicle (i.e., a "rover") is made available to the astronauts, there will still be problems which must be faced in clearing obstacles and in achieving high speed returns to the base in emergency situations. Although not currently a part of the Apollo program, the one man propulsion device should be made a part of this effort without delay.

The results of the subject program are directly applicable to the "Lunar Base Study" (Contract NAS-W-792) conducted by Boeing for NASA, as well as the Texas Instruments study to "Determine Optimum Measurements, Experiments, and Geological Studies to be Made on the Lunar Surface" (Contract NAS 9-2115). In addition, the subject program is closely related with, and is complimentary to the "Study to Develop Conceptual Designs and Preliminary Estimates of Development Schedules and Costs for Rocket-Powered Translunar Flying Vehicles" (Ref. RFP 1-4-21-01029-01, NASA MSFC dated 4/17/64). Although this study is for a two man flying vehicle for use in conjunction with MOLAB, some consideration should also be given to supplementing the larger vehicle locomotion capabilities with a one man propulsion device (for example, to make short exploration excursions, etc.). The subject study serves as an excellent background for such considerations.

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D. METHOD OF APPROACH

In order to achieve the program objectives which were discussed earlier, a study plan was established based upon the following tasks:

Task-I Operation and Performance Criteria

The purpose of the initial task was to define the operation and performance criteria for devices which could propel the astronaut in either free space or on the lunar surface. Typical free space and lunar surface missions were examined to gain a familiarity with the environmental and operational constraints, the areas wherein personal locomotion might be either needed or desired, the nature of the locomotion needs, and any restrictions related thereto.

Task-II Systems Interface Criteria

The interrelationships between the personal locomotion system and the other systems (e.g., the extravehicular suit, portable life support system, vehicle systems, etc.) were then reviewed to establish interface criteria for one man propulsion devices.

Task-III Design Concepts

Having established the basic criteria for propulsion devices for the contemplated missions, a study was then made of device concepts which would be applicable to the free space and lunar surface situations which might be encountered. Rough size and weight estimates were made for these concepts. These estimates were then used as input data for design trade-off studies which were aimed at answering the basic questions posed in the study guide-lines.

As part of the design trade-off studies, studies were made of the feasibility of utilizing a common system for both the lunar surface and free space applications, and of the need for automatic stabilization and control of the systems in both free space and on the lunar surface.

Task-IV Preliminary Design

The results of the design trade-off studies were then used to select the systems concepts which offered the most promise to meet the overall program objectives. These concepts were then used as a basis for the preliminary design efforts.

In addition to design layout drawings, mock-ups of the systems concepts selected were prepared and sufficient design details were worked out to define the units which evolved from the program.

Finally, to round out the program, studies were made of the potential methods which might be employed to both perform qualification testing on the devices and to train astronauts in their use.

Author

E. BASIC DATA GENERATED AND SIGNIFICANT RESULTS

Task-I Operation and Performance Criteria

The Task-I Analysis revealed a very definite need for one man propulsion devices in the current and future space programs. Requirements for such devices were found in both the planned portions of the lunar missions and in the potential situations of jeopardy which might be encountered in those missions. Range requirements for such devices in the early missions were found to be on the order of one mile on the lunar surface and under 1,000 feet in free space, with the lunar surface range requirements increasing as the explorations become more ambitious. Principal uses for the early devices will be to extend the astronaut's exploration capabilities and to provide him with a means of fast return to the base of operations in emergency situations.

Task-II Systems Interface Criteria

As a result of the Task-I analysis, it was determined that the most immediate one man locomotion needs would be best fulfilled by body-attached propulsion units. In considering the design problems of these units it became necessary to evaluate the influences which rocket nozzle exhaust plumes would have on the astronaut's pressure suit. A thorough analysis of the plume problem led to the conclusion that only mono-propellants could be used in these systems. Of the potential mono-propellants which were considered, only hydrazine and hydrogen peroxide were found to be satisfactory for the application. A study of the characteristics of these propellants and their influences on the system design indicated that hydrazine (using the new catalyst, Shell #405) was the best propellant to use in these systems.

In considering the integration and/or adaptation of the propulsion devices to the fully pressurized suit, the two foremost problems which were faced involved the plume temperature effects (which were mentioned earlier), and the methods of attaching the units to the suit. It was found that the plume temperature problem could be circumvented by proper selection of a propellant and by canting the thrusters relative to the centerline of the suited astronaut. A review of potential attachment methods indicated that the transmission of thrust forces and torques to the astronaut's torso would require some minor modification to the suit itself. These would consist mainly of reinforcement of the suit in certain areas and the addition of a load distribution system in the vicinity of the attachment points.

Examination of the interfaces between the portable life support system and the propulsion device revealed that there were no major problems involved in this area so long as the propulsion device was kept separate from the portable life support system (i.e., not integrated into the PLSS package).

In considering the stowage of the OMLS units and the vehicle ingress/egress problems which will face the astronauts in the use of the devices, it was concluded that the units should be stored external to the space vehicle for safety reasons and that vehicle ingress/egress by the astronaut while "wearing" a unit was out of the question for present hatch size limitations.

Task-III Design Concepts

As a result of studies of potential systems concepts which might fulfill the needs which are foreseen, five basic locomotion systems concepts were found to warrant further consideration:

1) A large "flying platform" for lunar surface use.

2) A "dual-purpose" unit, for both free space and lunar surface use.

3) A portable, "body-mounted" unit, optimized for the lunar surface activities associated with LEM.

4) A portable, "body-mounted" unit, optimized for the Apollo free space activities.

5) A simple, hand-held unit (used possibly in conjunction with a tether) for use in free space as an auxiliary to either 2) or 4).

As part of the study, a comparison was made of the relative merits of a "dual-purpose" unit (for both free space and lunar surface use) versus the two separate units. Consideration was given in this comparison to not only the weights of the units, but also to the weight penalties associated with the fuel required to transport the units to their points of application. This analysis showed that, whereas the combined system weights of the two separate units was greater than that of the "dual-purpose" unit, the two unit approach offered significant mission weight savings over the "dual-purpose" unit approach.

Further consideration was given in the study to the question of whether or not the propulsion devices should be incorporated into a common packaging arrangement with the portable life support system. The results of the analysis indicated that this design approach did not offer any significant advantages, and, furthermore, that it had some very decided disadvantages.

As part of the design analysis, computer studies were conducted of the system dynamics of lunar surface units. These studies were conducted on an existing contact analog facility which was modified to simulate the dynamics of the lunar surface units. It was determined during these studies that, whereas manual control could be used in lift and translation, automatic stabilization and control of attitude would be desirable during lunar flights.

Task-IV Preliminary Design

As a result of the earlier studies of potential one man propulsion devices, it was determined that the most immediate needs for personal locomotion in the space program could be satisfied by the use of portable, "body-mounted" propulsion systems. Furthermore, it was determined that at least two such systems would be required for the early missions -- one for use in free space, and the other for use on the lunar surface. Preliminary designs and full scale mock-ups were therefore prepared for these two systems.

The pertinent characteristics of the two systems which evolved from the preliminary design efforts are as follows:

	Lunar Surface OMLS Unit	Free Space OMLS Unit
Type of Unit	Body-mounted	Body-mounted
Propellant	Hydrazine	Hydrazine
Catalyst	Shell #405	Shell #405
Total Impulse	13,500 lbf.-sec.	3,000 lbf.-sec.
Thrusters	Four (4)-30 lbs.	Four (4)-10 lbs. Twelve (12)-2 1/2 lbs.
Total System Wgt. (Wet)	158.5 lbs.*	92.6 lbs.*
Net Payload Capability	363 lbs.* (max.)	317 lbs.* (max.)
Control and Stabilization	Manual translational control, automatic attitude hold (with manual override)	
Guidance and Navigation	Line of sight, direct visual piloting	

*Earth Weights

F. STUDY LIMITATIONS

The absence of factual information on the physical makeup of the lunar surface and its trafficability by vehicles and man on foot imposed a definite limitation on the study. Speculative information on the lunar surface characteristics had to be employed in arriving at predicted vehicle and pedestrian capabilities. As it turned out, however, this limitation did not affect the validity of the study results.

The study was based upon the present pressure suit and portable life support system characteristics. In this sense, some limitations were imposed on the systems concepts which resulted. An attempt was made throughout the study to speculate as to the nature of the changes which will insue in suit and PLSS designs in the near future, but such anticipations were not carried fully into the design phases of the program, since the changes are by no means certain and their use would certainly weaken the foundations upon which the resultant designs were based.

The portions of the study dealing with the integration of the propulsion device into the vehicle systems (e.g., Apollo and LEM) was hampered somewhat by the fact that the vehicle designs had not yet been frozen sufficiently to accurately determine the exact interface relationships which would exist. However, it is felt that this was not a serious limitation on the study and that the general conclusions drawn in this area are still valid.

As a result of the mission analysis and design trade-off studies (which were conducted during the early part of the program), five basic design concepts of one man locomotion systems were found to warrant further study. Limitations in program funds and in the time available to complete the study permitted the pursuit of only two of these concepts during the preliminary design phase of the program. The two concepts which were selected for further study were chosen on the basis that they would find most immediate use in the space program and that a study of their characteristics would yield the most design information on such systems for use in the future space programs. In a sense, this did limit the preliminary design effort, but did not compromise the program objectives in any way. The other three concepts were defined sufficiently to allow further consideration of them at a later date.

G. IMPLICATIONS FOR RESEARCH

As a result of the subject study program, a number of problem areas were uncovered which suggested areas of potential research effort. These are summarized as follows:

Biotechnology and Human Research

Of particular concern in both free space and lunar surface maneuvers is the ability of the suited astronaut to make use of his sensory capacities in the navigation and guidance aspects of the maneuvers. A research program is suggested wherein a suited astronaut would be subjected to simulated visual conditions which might be encountered in the maneuvers to determine his ability to perceive objects and guide himself to a target under those conditions.

A second area of concern under the general category of human research is the question of the ability of a suited astronaut to retain sufficient balance and stability to effect a gentle landing under lunar gravitational conditions. A research program is suggested wherein the lunar gravitational conditions and the suit encumbrances are imposed on a man and a study is made of his ability to retain balance when descending from predetermined heights, at various approach angles, and at various landing speeds.

Electronic and Control

The absence of an atmosphere on the lunar surface precludes the use of some of the simpler techniques for sensing altitude and speed which are currently used here on Earth. A research program is in order whereby other phenomena, which are natural to the lunar environment, might be exploited for these purposes.

Propulsion and Power Generation

During the course of the study program, a comprehensive analysis was made of the effects of rocket nozzle exhaust plumes on suit surface temperatures in a vacuum environment. The results of this analysis should be verified by an experimental program prior to completing a detail design of a unit for operational use in the space program. As far as it is known, all of the experimental investigations which have been conducted to date in this area have not utilized a high enough vacuum to reasonably approach the plume conditions which would be encountered in space. A program is in order whereby the plume effects can be examined under more natural environmental conditions.

H. SUGGESTED ADDITIONAL EFFORT

In addition to the suggestions which were made previously with regard to desirable research programs, the following programs are recommended as follow-on efforts to the study just completed:

Hardware Development Efforts

The current study has shown the desirability of, and the need for, a hand-held unit which can be used as a general-purpose propulsion device for close proximity maneuvering in free space. The design and construction of such a device should be quite straightforward and does not require any further study. It is therefore recommended that the full development of such a unit be initiated as soon as possible.

Similarly, the longer-range, body-mounted free space one man propulsion device which evolved from the program does not appear to require any further study effort. The need for such a unit in the current space program is immediate, and it is recommended that a full development program in this area be also initiated as soon as possible.

Finally, it would be highly desirable if single-hand controller could be developed which would be applicable to both of the one man locomotion units which evolved from the preliminary design portion of the program, as well as future flying platform units. This controller would be operable with either hand and would permit the astronaut to effect changes in attitude, lift, and translation by virtue of simple arm and wrist motions. An important aspect of a development program in this area would be the assessment of arm, wrist, and finger dexterities under the influence of suit hindrances (in the pressurized mode) and the reconciliation of these influences with the motions required for adequate control. It is therefore recommended that functional mockups of several of the more promising controller concepts be fabricated and tested on a simulator with the operator wearing a fully pressurized suit.

Detail Design and Test Efforts

It is recommended that a detail design and prototype construction program be initiated on the lunar surface one man locomotion system which evolved from the subject study, and that this unit be subjected to limited testing on Earth prior to proceeding with the final design and development of such a unit for use in the lunar missions.

Additional Study Efforts

It is recommended that the further studies be made of a flying platform device for use in future lunar exploration missions. These studies should not only include the preliminary design of such a unit, but also the simulation of its flight dynamic characteristics on a computer and a study of the stabilization and control techniques which need to be employed in its use on the lunar surface.